Inventory & Monitoring Program
Pacific Island Network
Monitoring Plan

Appendix A: Invertebrate Fauna Report

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Pacific Island Network (PACN)

Territory of Guam
War in the Pacific National Historical Park (WAPA)

Commonwealth of the Northern Mariana Islands
American Memorial Park, Saipan (AMME)

Territory of American Samoa
National Park of American Samoa (NPSA)

State of Hawaii
USS Arizona Memorial, Oahu (USAR)
Kalaupapa National Historical Park, Molokai (KALA)
Haleakala National Park, Maui (HALE)
Ala Kahakai National Historic Trail, Hawaii (ALKA)
Puukohola Heiau National Historic Site, Hawaii (PUHE)
Kaloko-Honokohau National Historical Park, Hawaii (KAHO)
Puuhonua o Honaunau National Historical Park, Hawaii (PUHO)
Hawaii Volcanoes National Park, Hawaii (HAVO)

http://science.nature.nps.gov/im/units/pacn/monitoring/plan/2004/

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EXECUTIVE SUMMARY

This report outlines the status and needs of invertebrate monitoring in the Pacific Islands Network (PACN). The extraordinary diversity and evolutionary significance of the Pacific Islands' terrestrial and freshwater invertebrate fauna – nearly 4,000 species have been recorded from the Hawaii parks alone – lends special importance to its conservation. The degree to which it is threatened by invasive species, habitat loss, and other stressors gives additional urgency. Cloud forests, anchialine ponds, volcanic moonscapes and caves, and other unique habitats make the parks centers of diversity for the region. While invertebrates have historically been under-monitored in PACN parks, their importance is now being recognized. Monitoring will provide critical information and tools for better conservation and management of invertebrates in the future.

Ala Kahakai National Historic Trail (ALKA). The invertebrate resources of the newly-designated, 175-mile-long Ala Kahakai Trail have not been inventoried. The path, extent, and boundaries of the trail have not yet been defined.

American Memorial Park (AMME). AMME is a 54 hectare (133 acre) coastal park on the island of Saipan in the Northern Marianas. No inventory of invertebrates has been undertaken in AMME. The park is unlikely to support a diverse assemblage of native invertebrates because it is dominated by alien plant species. However, it contains a rare near-native mangrove wetland which should be inventoried for aquatic insects. A species of rare partulid snail was recently discovered in the wetland. The status of the alien ant community also deserves attention.

Haleakala National Park (HALE). HALE on Maui has been the subject of several inventories for invertebrates, but the invertebrate resources of much of the park remain poorly known. Its 11,800 ha (29,100 ac) cover extensive elevational and moisture gradients on Haleakala and a rich range of invertebrate habitat. There are approximately 15 threatened and endangered plant species that serve as obligate hosts for native arthropods. Several alien invertebrates have been identified as real or potential stressors in these communities, including ants, mosquitos, yellowjacket wasps, parasitoids and slugs. HALE and its cooperators have been monitoring Argentine ants and western yellowjacket wasps since the 1980s.

Hawaii Volcanoes National Park (HAVO). HAVO on the island of Hawaii has the most extensive information on its invertebrate fauna. Perkins collected and reported on the insect fauna of Kilauea at the turn of the century and HAVO was the subject of an intensive altitudinal survey of terrestrial invertebrates under the US International Biological Program from 1971 to 1976. A field research station has also supported additional smaller invertebrate surveys and the park maintains an invertebrate specimen collection begun in the 1940's as part of its natural history collection. As a result, HAVO has a greater invertebrate specimen base than any other park in the network. Like HALE, HAVO has a diverse range of habitats along often steep moisture and temperature gradients. The greatest diversity of endemic invertebrates occurs in the montane wet and mesic forests in older kipukas, the East Rift Zone of Kilauea Volcano, and the disjunct Olaa Forest. Many of the rare and endangered plant species in this area support small communities of host-plant specific endemic arthropods, and a number of species of concern are known from the park. HAVO and its cooperators have been monitoring yellowjacket wasps since the late 1980s.

Kaloko-Honokohau National Historical Park (KAHO). KAHO is a coastal park of approximately 470 ha (1,160 ac) on the island of Hawaii. Much of the vegetation is exotic, and

this is reflected in the dominance of introduced insects. An inventory of the insect fauna was carried out in 1992. Anchialine ponds and Hawaiian fishponds in the park support an endemic invertebrate fauna, including several types of shrimp, prawns, and the candidate endangered damselfly *Megalagrion xanthomelas*. These ponds are vulnerable to human-caused damage and introduced fish, and are strong candidates for monitoring.

Kalaupapa National Historical Park (KALA). KALA is a park of approximately 4,365 ha (10,778 ac) on the island of Molokai, established to preserve the cultural landscape of a Hansen's disease colony. The insect fauna is virtually unknown, but the variety of native vegetation found there suggests that it has the potential to harbor many interesting species. This is especially true of the Puu Alii region, which contains a large area of montane wet forest. Other areas have probably been invaded by exotic ants but may still harbor native insects, particularly stream-breeding species and bees. Two rare damselfly species are known from Waikolu stream. Aquatic species in the streams, including damselflies and true flies, are particularly suited to long-term monitoring programs. As elsewhere, loss of habitat as a result of invasive plants and predation by introduced ants are the most important stressors on native invertebrates here.

National Park of American Samoa (NPSA). NPSA includes more than 3,640 ha (9,000 ac) in four units on four islands of American Samoa. The park contains one of the last remaining undisturbed paleotropical rain forests. The insects are poorly known, but the intact rain forest suggests a diverse fauna is present. A diverse group of native land snails exists in Samoa, including the candidate endangered *Eua zebrina* and three species of concern, as well as several other rare species. It has been recommended that these be monitored for population declines.

Puukohola Heiau National Historical Site (PUHE). PUHE is a 35 ha (86 ac) coastal park on the island of Hawaii established to protect Hawaiian culture and historical sites. Natural vegetation has been largely replaced by alien vegetation, and many native species exist in the park only as plantings by park staff. As a result, it also has the fewest native invertebrate species; a 1992 inventory found only two native insects.

Puuhonua o Honaunau National Historical Park (PUHO). PUHO is comprised of 74 ha (182 ac) on the coast of Hawaii Island. It was established to protect Hawaiian culture and historical sites. Natural vegetation has largely been replaced by alien species. Native insect diversity is intermediate between that of KAHO and PUHE, consisting primarily of aquatic flies but also with a few other species; the 1992 inventory found 125 exotic species and 13 natives. Native plant restoration plots should be monitored periodically for recolonization by endemic insects.

USS Arizona Memorial (USAR). The USS Arizona Memorial is a 4 ha (10 ac) site in Pearl Harbor, Oahu. The land portion was created from fill on coastal wetland and no native non-marine resources are present. This area is not actively managed for natural resources.

War in the Pacific National Historical Park (WAPA). WAPA consists of 825 ha (2,037 ac) dispersed over seven units in Guam, Mariana Islands. The park commemorates the campaigns of the Pacific theater of WWII. It includes a variety of native habitats, as well as disturbed areas. Introduced pests have increased dramatically with the reduction in bird, lizard, and bat populations due to the alien brown tree snake. Four land snails in the family Partulidae are historically known from Guam; one is considered extinct, and the other three are candidate endangered species. Guam supports a large insect fauna, including two rare butterfly species. Mosquitoes are a problem during the wet season, and can spread diseases such as malaria, dengue fever, and filariasis. All four groups (invasive aliens, snails, butterflies, and mosquitoes) are priorities for monitoring.

INTRODUCTION

A. SCOPE OF TOPIC AREA

This section covers monitoring of terrestrial and non-marine aquatic invertebrates. "Invertebrate monitoring" includes tracking alien and native invertebrate species populations and changes in invertebrate communities. Population monitoring addresses changes in populations of incipient and established invasive species, intentional introductions, keystone native species, and rare species including Species of Concern and candidate Endangered species. It also includes detecting changes in terrestrial and aquatic invertebrate communities over time and across environmental gradients altered by patterns of long-term climate change. Community monitoring includes quantitative monitoring of invertebrate species assemblages as well as vegetation mapping of the spatial distribution of plant communities. Community monitoring typically addresses alteration of species composition with changes in vegetation communities (such as successional patterns), ungulate disturbance, invasion of alien invertebrates, recovery after alien species control and ecological restoration efforts, and tracking long-term trends in species composition.

B. BACKGROUND

Invertebrate monitoring in the PACN is a high priority relative to most mainland National Parks. Particularly in Hawaii, insects and snails are disproportionately important in both ecosystem function and biological diversity as a result of the extremely depauperate vertebrate fauna and the extraordinary radiations that have taken place in multiple insect groups. In addition, the effects of invasive invertebrates and plants are multiplied due to the lower likelihood of a natural enemy being already present.

There are 9,897 species of terrestrial arthropods recorded from the major Hawaiian Islands, including 5,732 species that are endemic to these islands. When other major groups of invertebrates are included, such as molluscs, crustaceans, and annelids, biodiversity approaches a figure that is an order of magnitude greater than species of native flowering plants, and greater than all bird species in the world. The challenge of the National Park Service is to identify, prioritize, and implement invertebrate monitoring programs in the Pacific, while recognizing that a tremendous proportion of the biological diversity represented by invertebrates remains poorly known and uninventoried. Taxonomic impediments (lack of identification keys and many undescribed species) and lack of inventory data are greater outside of the Hawaiian Islands, and resource basic inventories of invertebrates may have to precede the development of monitoring programs for sensitive native invertebrate fauna in western Pacific parks, such as NPSA. Ten of the 11 National Parks in the Pacific Island network have habitat that can support native terrestrial and freshwater aquatic invertebrates. All parks in the network can contribute to monitoring programs for invasive alien invertebrates, such as incipient invasions of ants.

C. MONITORING GOALS AND OBJECTIVES

The overall goals of monitoring are set forth in the establishment of the I&M program and the PACN (see Monitoring Plan). On a practical level, a monitoring program will provide data for the following objectives:

- An early warning system for managers about newly invasive invertebrate species, changes in established alien invertebrate populations and invertebrate communities, and loss of rare or key native species to help develop effective control and mitigation measures.
- Information about status and trends in invertebrate populations and communities to better understand them and develop strategies for alien species control and ecological restoration programs.
- Feedback to managers about effects of disturbance, alien species control, ecological restoration, and rare species management programs to help them manage adaptively and provide decision support.
- Assess effects of habitat fragmentation, develop strategies for conservation partnerships, and evaluate landscape level restoration attempts.
- Measure progress and meet reporting requirement of the performance management system, Endangered Species Act, and other Congressional requirements.

Long-term ecological monitoring of invertebrate communities and species is relatively new, compared to monitoring that has been done for plants and birds. However, invertebrates are now being widely recognized as an important component of monitoring programs. Monitoring is especially critical in areas such as Hawaii where the endemic insect fauna is so diverse and unique, and the direct and indirect threats to them are so great. In addition to monitoring diversity and abundance of invertebrates themselves, they can be used as indicators for other ecological conditions, such as water quality and invasive species impact. Because invertebrate generation times are faster than those of vertebrates and plants, invertebrate monitoring programs can serve as important early warning systems for detecting habitat degradation on a timescale where intervention and recovery can occur more rapidly.

As foreseen here, the monitoring program will operate within an adaptive management framework to help establish and evaluate alien species control, ecological restoration, and rare species recovery programs. Some monitoring activities will provide long-term monitoring apart from specific management treatments but much of it will be tied directly to management. Integration with research organizations, especially in areas such as invasive species where rapid response is needed, is also a critical component of monitoring.

LEGISLATION AND POLICY

As a federal agency, the NPS operates under a hierarchy of legislative mandates, including federal laws, executive orders, Department of the Interior and NPS policies and directives, as well as county, state, commonwealth, and territorial regulations. Further, management of submerged resources is complicated by jurisdictional or administrative issues that are often managerially more challenging than similar issues on land. These complexities require the NPS to cooperate with numerous and often overlapping federal and local agencies to achieve its objectives.

A. I&M – NATURAL RESOURCE CHALLENGE

The Natural Resource Challenge (NRC), initiated in 1999, is an action plan for preserving natural resources through the National Park Service. The NRC assisted NPS to establish 32 Inventory and Monitoring networks, which includes 270 National Parks. In the Networks, parks are grouped that share geographical and natural resource characteristics. The Inventory and Monitoring (I&M) Program is designed to first complete basic inventories of natural resources in parks, on which to base long-term monitoring efforts. Monitoring programs are based on monitoring critical parameters (Vital Signs) within each network to incorporate into natural resource management and decision-making. Vital Signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems.

B. INTERNATIONAL

The Convention on International Trade in Endangered Species (CITES) is intended to ensure that international trade does not threaten the existence or survival of endangered or threatened species. It regulates the trade of species listed as endangered or threatened by the country of origin, the importing country, or any countries that the species might travel or pass through. Of the 14 species and 8 genera of terrestrial invertebrates listed in CITES, none are found within the parks. The *Achatinella* land snails of Oahu are included because of their colorful shells, a quality shared with the closely related *Partulina* found in KALA.

C. FEDERAL

1. Legislation

Several federal laws have broad applicability to conservation and management of both invertebrate diversity in parks and invasive species, notably the following:

- National Park Service Organic Act (1916) – This Act formed the National Park System to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." http://www.nps.gov/legacy/organic-act.htm
- National Environmental Policy Act (1969) – Mandates that all federal projects and actions consider environmental effects of proposed activities, and provides for public input. http://ceq.eh.doe.gov/nepa/regs/nepa/nepaeqia.htm
- General Authorities Act (1970) – Reinforced the Organic Act, and stated that all park lands are united by a common preservation purpose regardless of title or designation. http://www.nps.gov/legacy/legacy.html
- Endangered Species Act (1973) – Provides protection for of fish, wildlife and plant species that are listed as threatened or endangered in the U.S. or elsewhere. Guidance is provided for listing species, as well as for establishing recovery plans and designating critical habitat for listed species. Procedures for federal agencies to follow when taking actions that may jeopardize listed species are outlined. The Act also includes provision for exceptions and exemptions. http://endangered.fws.gov/ESA/ESA.html
- National Parks Omnibus Management Act (1998) – Clarified the role of NPS as a conservation and science agency. Among the items it specifically mandated were the

establishment of an inventory and monitoring program to obtain baseline information on natural resources, the development of a broad, rigorous scientific research program which could be expanded by establishing cooperative agreements with outside groups and the hiring and training of scientists within the NPS. Additionally, NPOMA granted protection for key natural resources within the parks by restricting sensitive information from release under the Freedom of Information Act. http://www4.law.cornell.edu/uscode/16/ch79.html

The only Pacific Island insect listed under the Endangered Species Act, Blackburn's sphinx moth (*Manduca blackburni*) is now restricted to dry forest on the south slope of Maui and is not known to occur in any of the parks. There are currently 263 arthropod and 73 snail species of concern in Hawaii (Hawaii Biological Survey, 2000). Several candidate endangered species, including members of the genera *Drosophila*, *Emperoptera* (both flies), and *Megalagrion* (damselflies), and a large number of SOCs occur in or near HALE, HAVO, and KALA. SOC insects and the candidate endangered anchialine pond shrimp *Metabetaeus lohena* are present in KAHO. PUHE and PUHO are not known to contain any endangered or SOC invertebrates. The remaining parks have been poorly inventoried and are not known to contain any insect SOCs. Among snails, the candidate endangered *Eua zebrina* and *Ostodes strigatus*, and seven SOCs in the genera *Diastole*, *Samoana*, and *Trochomorpha*, are found in or near NPSA. One species of *Partula* and one *Samoana*, both candidates, are found on Guam in or near WAPA; a second *Partula* occurs in AMME. Four SOC tree snails in the genus *Partulina* are found in or near KALA. Many more species are known to be rare and belong on the endangered or SOC list, but have not been adequately investigated.

2. Executive Orders

The primary executive order pertaining to invertebrate conservation is Executive Order 13112: Invasive Species (1999), which states that "Federal agencies whose actions may affect the status of invasive species shall: (1) identify such actions, (2) use relevant programs and authorities to prevent, control, monitor, and research such species, and (3) not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere."

D. National Park Service

1. Park Enabling Legislation

None of the Pacific National Parks have specific language regarding invertebrates. Lands now included in HAVO and HALE were established under the same legislation, which provides protection for "all timber, birds, mineral deposits, and natural curiosities or wonders" within the park. PUHE, PUHO and KAHO were established to protect Hawaiian cultural and historical sites, and the era of Hawaiian inhabitation (especially 1100-1900) is the model for the historical landscape. The legislation for KALA states that "natural features" are to be researched, preserved and maintained. The act establishing NPSA recognized the importance of the Park's tropical forest as one of the last remaining undisturbed paleotropical forests and as habitat for Pacific flying foxes, and stated that the park should "preserve the ecological balance" of the forest. ALKA legislation does not refer to the natural resources of the 175-mile historic trail. The enabling legislation of WAPA states that the campaigns of the Pacific theater of World War

II are to be commemorated, and the natural and scenic values of Guam are to be conserved. Likewise, AMME was established on Saipan to honor those who died in the WWII Mariana Islands campaign, and no natural resources management is specified.

2. NPS Management Policies

NPS Management Policies were revised in 2000 and contain extensive guidance on Natural Resource Management (see Chapter 4 of the NPS Management Policies Handbook). All monitoring activities must fall within the framework of these Management Policies. The Natural Resource Management Guideline, NPS-77 (currently being revised as RM-77), provides further details and instructions on management of native and exotic animals, caves (including lava tubes), and endangered, threatened, and rare species.

3. Director's Orders

Several DOI and NPS directives and documents provide guidance and support for natural resource management.

- Memorandum to Secretary of the Interior from the Solicitor (16 April 1998): This memorandum analyzes the Secretary's legal duty to protect parks from activities on non-NPS land adjacent to park boundaries. While not explicit in the Redwood Amendment, this memo provides support for involvement in natural resource issues lying outside the park boundary.
- D.O. 55 (2000): D.O. 55 further clarifies language within the NPS Organic Act and the 1970 Act for Administration including the Redwood Amendment by reiterating the single mission of the NPS: to preserve resources. This Director's Order also clarifies what constitutes impairment, park resources and values, and provides guidance for decision making, including requiring scientific data in accordance with the National Parks Omnibus and Management Act.

4. Park Specific Management Policies

Resource management in HALE and HAVO is primarily concerned with natural resource conservation, and they have expended considerable effort in protection and restoration of the native biota. Both parks also maintain active field research stations, operating under USGS, that perform research both inside and outside the parks. AMME, KAHO, KALA, PUHE, PUHO, and WAPA have been primarily focused on cultural resources, but major programs to remove alien vegetation and restore native habitats have been undertaken or are underway at KAHO and KALA. Management at NPSA has focused on marine resources, but the park has recently established vegetation monitoring plots. ALKA and USAR are currently not actively managing terrestrial natural resources.

5. Park Planning Documents

Park General Management Plans (GMPs) and Resource Management Plans (RMPs) provide general information on priorities for each park. Native insects have relatively high priority in the HALE and HAVO RMPs. Both control of invasive species, such as the Argentine ant (*Linepithema humile*) and western yellowjacket (*Vespula pensylvanica*), and conservation of natives are cited as important management issues. Invertebrates are also prominent in the KALA plan, which cites lack of information about arthropods and molluscs as a major problem and states that they will be inventoried in Special Ecological Areas (SEAs). The KAHO and PUHE plans refer only to invertebrates of anchialine ponds, where most native species in the parks are found. They state that a coordinated pond management plan will be developed for both parks. In addition to anchialine pond fauna, the PUHO RMP mentions the native insect fauna and its decline in the park. However, with so few native insect species in the park, no specific actions on invertebrates are recommended. The NPSA GMP cites (among others) tree snails and butterflies as being priorities for inventories and determination of population status. A general lack of information about invertebrates is also considered a management issue. Terrestrial invertebrates are not or rarely mentioned in the plans for AMME, USAR, and WAPA.

E. STATE, COMMONWEALTH, AND TERRITORIAL

1. American Samoa

The American Samoa Code Annotated, under Title 24, includes a number of statutes concerning general (physical) environmental quality. There are also two provisions for biological conservation. Chapter 07 establishes a natural resources commission for the purpose of conservation and management of federally listed endangered species, as well as those whose harvest is deemed in need of regulation. Chapter 10 establishes a system of inspections for detection and control of coconut beetle, a serious pest of coconut crops.

2. Commonwealth of the Northern Mariana Islands

The CNMI Division of Fish and Wildlife is mandated by local law (Public Law 2-51) to conserve fish, game and wildlife and to protect endangered and threatened species. A number of non-federally listed species are listed as endangered by the DFW, but none are invertebrates. The snails *Partula gibba* and *Samoana fragilis* (found in AMME and possibly WAPA respectively) are listed as Species of Special Concern, along with the coconut crab (*Birgus latro*) and the butterflies *Vagrans egestina* and *Hypolimnas octucula mariannensis*.

3. Guam

The Endangered Species Act of Guam (PL 15-36) provides for local designation of endangered species as well as recognizing federally listed species. It authorizes the Department of Agriculture to list, study, and propose rules for endangered species, and to acquire land for their protection.

4. Hawaii

Hawaii also has legislation that allows for the listing of endangered species at the State level. To date, no invertebrates other than those recognized on Federal endangered species lists have been listed as threatened or endangered. The State of Hawaii also has injurious wildlife regulations that recognize some alien animals as harmful to agriculture or native animals and plants, and prohibits their introduction to new areas (State of Hawaii, 1997). Currently, all terrestrial invertebrates on the injurious species list are molluscs: the European brown snail (*Helix* *conspersa*), giant African snail (*Achatina fulica*), apple snails (*Pomacea* and related genera), and two species introduced to control the African snail, *Euglandina rosea* and *Gonaxis kibweziensis*.

ECOLOGICAL CONTEXT

A. GEOGRAPHY

All the PACN network parks are located on tropical islands in the Pacific Ocean (Figure 1). Eight of the parks are in the Hawaiian Islands in the Central Pacific between 19 and 22 degrees North latitude. HAVO, KAHO, PUHE, PUHO, and the recently designated ALKA are on the island of Hawaii, the youngest of the main Hawaiian Islands at the southern and eastern end of the archipelago. HAVO is located on the southeast slope of Hawaii Island, where it extends from sea level to the summits of Kilauea and Mauna Loa Volcanoes. The newly designated Kahuku unit of HAVO is positioned on southern Mauna Loa and extends down both the eastern and western flanks of the volcano. PUHE, KAHO, and PUHO are coastal parks of the western side of the island. KAHO is centrally located with PUHE to the north and PUHO to the south. HALE is on Maui, the second youngest Hawaiian Island. HALE extends from sea level to the

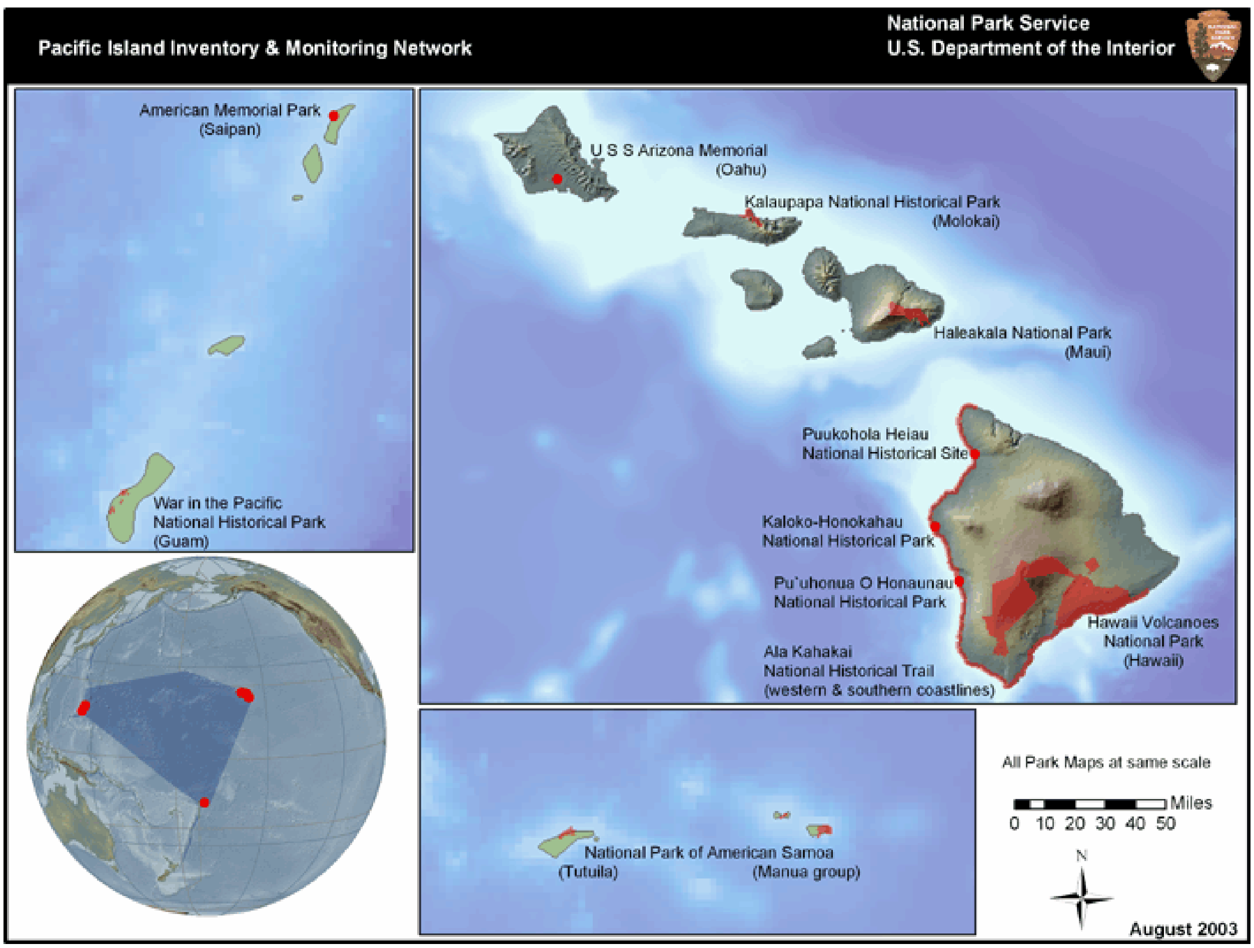


Figure 1. Pacific Island Inventory and Monitoring Network.

summit of East Maui. KALA is on a peninsula projecting from the north shore of Molokai, centrally located in the main Hawaiian Islands. USAR is within Pearl Harbor on southern or leeward Oahu. Two PACN parks are situated in the western Pacific Ocean between 13 and 15 degrees north latitude in Micronesia. WAPA is on the western side of the island of Guam and AMME is on the west coast of Saipan, part of the Commonwealth of the Northern Mariana Islands (CNMI). NPSA is on the Polynesian islands of American Samoa, approximately 13 degrees south latitude. One unit of NPSA is on the island of Tutuila, and three others are on Tau, Ofu, and Olosega of the Manua Island group 96 km (60 miles) east of Tutuila.

B. Geology

The parks of the Western Pacific (WAPA, AMME) are on the islands of Guam and Saipan which have long-extinct volcanoes. These islands have complicated geologic origins involving both volcanism and subduction of the Marianas Trench. Hence, the northern half of Guam and portions of Saipan have limestone substrates elevated above a weathered volcanic base. WAPA units are on the volcanic substrates of the southern half of Guam, and at least one unit includes elevated limestone caps.

The islands of American Samoa and Hawaii are oceanic volcanic islands arising from hotspots. The oldest of the Samoan Islands are dated at more than two million years, but there was volcanic activity between Tau and Olosega approximately 150 years ago (Whistler, 1994). In Hawaii, HALE protects the summit of the inactive Haleakala Volcano and its impressive crater, which is the result of stream erosion, the merging of Kaupo and Keanae Valleys, and subsequent volcanic activity. KALA encompasses the Kalaupapa peninsula, formed on the north shore of Molokai during the Pleistocene (MacDonald and Abbott, 1970). The volcanoes on both Molokai and Oahu are extinct.

The five parks on Hawaii Island are on active or dormant volcanoes. A significant portion of HAVO is covered with recent lava flows that are sparsely vegetated. HAVO also contains the rift zones and summit calderas of both Mauna Loa and Kilauea Volcanoes, two of the most active volcanoes on earth. PUHO is on prehistoric pahoehoe flows of Mauna Loa, and PUHE substrates are old weathered soils of Kohala Volcano. All substrates of KAHO are flows from Hualalai Volcano less than 10,000 years old, including one sparsely-vegetated lava flow dated at 1,000-3,000 years (Moore et al., 1987).

C. Elevation Gradients

Among the Hawaiian parks, HAVO and HALE have the greatest elevational range, extending from sea level to the summits of tall volcanoes >3,000 m (>10,000 ft) in elevation. KALA has an elevational range from sea level to almost 1,220 m (4,000 ft) elevation. The three parks of leeward Hawaii Island are coastal parks and extend upslope less than 100 m in elevation. ALKA is also in the coastal lowlands of western and southern Hawaii Island.

Among the three Western Pacific parks, AMME is restricted to coastal lowlands on the western shore of Saipan. WAPA includes both coastal units and inland sites on the slopes of Mt. Alifan and Mt. Tenjo, with one unit extending above 305 m (1,000 ft) in elevation. NPSA is composed of four units: Ofu and Olosega are largely coastal but the Tutuila and Tau units range from sea level to 491 m (1,610 ft) and 966 m (3,170 ft) elevation, respectively. The planned expansion of

NPSA on Ofu and Olosega will include the summits of both islands, which are 499 m (1,621 ft) and 639 m (2,096 ft) respectively.

D. Rainfall and Climate

The two largest Hawaiian parks, HAVO and HALE, include within their boundaries several climatic zones with a range of rainfall regimes. HAVO contains two of the four rainfall minima of Hawaii Island, the Kau Desert with mean annual rainfall <750 mm and the interior lands of Mauna Loa. The highest mean annual rainfall within the park is found in Olaa Tract, a rain forest with >4,000 mm per year (Giambelluca et al., 1986). In general, the eastern windward portion of HAVO has high rainfall, which diminishes upslope, particularly above the trade wind inversion layer near 1,830 m (6,000 ft) elevation. The upper elevations of the park are moist to very dry, and the summit of Mauna Loa receives on average <500 mm precipitation. The leeward, western portions of HAVO are in rain shadows of Mauna Loa and Kilauea summit, and are typically dry.

HALE also has a range of climates, as it extends from sea level on the windward, eastern slope of Haleakala to the summit of East Maui. This park also includes lands in the leeward rain shadow of Haleakala, down to 1,220 m (4,000 ft) elevation. Annual precipitation in the park varies from 1,250 mm in the Crater, the southern slope, and Kaupo Gap to >6,000 mm on the upper northeastern slopes of Haleakala. KALA, on the north shore of Molokai receives 1,000 mm of precipitation annually at sea level and >3,000 mm at the upper elevations of Waikolu Valley (Giambelluca et al., 1986). The USAR on Oahu is located within Pearl Harbor on the dry leeward side of the island in an area than has on average 600 mm rainfall per year.

The four Hawaii Island parks are in relatively low rainfall areas with constant warm temperatures and pronounced daily wind patterns of land and sea breezes (Blumenstock and Price, 1967). KAHO has a mean annual rainfall of approximately 600 mm and a seasonal climate with higher rainfall during summer months (Canfield, 1990). The climate of PUHO is similar to that of KAHO, with mean annual precipitation of 659 mm. PUHE is located within one of the four rainfall minima of the island of Hawaii and receives <250 mm of rain annually (Giambelluca et al., 1986). Because ALKA covers a large linear coastal transect along West Hawaii, the rainfall pattern is variable.

The climate of Guam and the Northern Marianas, including Saipan, is warm, wet, and tropical. Temperature varies between 70° and 90° F. Relative humidity is high, often exceeding 80% and seldom falling below 50%. The rainfall pattern is strongly seasonal with a wet season from July to November and a pronounced dry season from December to June. Average annual rainfall of the Marianas is 2,160 mm (85 in) (Baker, 1951), and on Guam the annual mean is 2,175 mm (Mueller-Dombois and Fosberg, 1998). Typhoons are yearly events, which occur during the monsoonal wet season. Trade winds blow from the northeast, but easterly and southeasterly winds prevail during several months in the spring (Baker, 1951). Because Guam and the Marianas are relatively low islands, there is no pronounced rain shadow effect, and leeward shores are not drier than those of the windward sides (Mueller-Dombois and Fosberg, 1998).

NPSA has a warm tropical climate with little seasonal variation in temperature. Rainfall is high in the four units of the park. On Tutuila, annual rainfall averages 3,200 mm (at the airport), and may be even higher on the upper mountain slopes within the park. Rainfall is seasonal with greater monthly means from October to May and a dry season from June to September.

Hurricanes are occasional but not annual events (Whistler, 1994). Tau Island unit is only about 96 km (60 miles) east of Tutuila and shares its warm and wet tropical climate. Tau average rainfall is more than 2,500 mm per year and is highest in December. The dry season is June to September, and droughts sometimes occur on the island (Whistler, 1992).

E. NATURAL AND EXISTING VEGETATION

Native invertebrates are largely restricted to areas of predominantly native vegetation. Thus, their fate is intimately connected with the existence, diversity, and health of native plant communities. Many species of insects are host-specific, and may be extirpated even if their host plant persists at low population levels. This is especially true for groups such as *Drosophila*, moths, and planthoppers. They in turn are often the hosts of specialist predators and parasitoids, which follow their host into extinction. Many of the plant communities found in the Pacific parks are endangered, and some among the most intact of their type.

Among the Hawaii parks, HALE and HAVO have the greatest diversity of vegetation types and the highest proportion of native vegetation. HAVO contains coastal strand vegetation, remnant lowland wet and dry forest, dry open woodlands, early successional vegetation on lava flows, montane rain forest, montane mesic forest, montane dry forest, subalpine forest and shrubland, and a sparsely vegetated alpine zone. With the acquisition of Kahuku, HAVO now contains the largest population of Mauna Loa silverswords (*Argyroxiphium kauense*). HALE has coastal vegetation, highly disturbed lowland rain forest and mesic forest, intact lowland and montane rain and cloud forests, montane bogs, subalpine grasslands and shrublands, alpine aeolian cinder fields, montane dry forest remnants, and leeward mesic shrublands. HALE also supports both perennial and intermittent streams, pools and subalpine lakes. There are approximately 15 threatened and endangered plant species, such as Haleakala silversword (*Argyroxiphium sandwicense*), that support communities of obligately associated native arthropods. KALA has coastal strand, loulu palm (*Pritchardia*) coastal forest, remnant lowland mesic forest, native vegetation on cliff faces, and lowland and montane wet forest. Natural vegetation of the three Kona historical parks (PUHE, KAHO, and PUHO) has been largely replaced by exotic plants except for coastal strand and wetland vegetation. AMME is largely covered by alien secondary vegetation except for coastal strand and a mangrove wetland. The latter is one of the last remaining in the Marianas. WAPA contains remnant limestone forest, savanna, and ravine or riverine forest, as well as disturbed areas of secondary vegetation. The four units of NPSA have vegetation ranging from coastal strand and littoral forest to *Dysoxlum* lowland rain forest, montane rain forest, and summit scrub dominated by ferns.

F. NATURAL INVERTEBRATE RESOURCES

1. Insects

The Hawaiian Islands contain large radiations from nearly all major insect groups, but the total of over 6,000 native species is estimated to derive from no more than 250 colonists. This fauna is unique in the world, with 98.3% of the species restricted to Hawaii. No other island group contains such extensive insular radiations. Some insect groups with over 50 species in Hawaii are *Campsicnemus*, *Drosophila*, and *Scaptomyza* flies; *Laupala* and *Trigonidium* crickets; *Kilauella* and *Ptycta* barklice; *Nesophrosyne* and *Nesosydne* planthoppers; *Blackburnia*, *Mecyclothorax*, *Plagithmysus*, *Prosopeus*, and *Proterhinus* beetles; *Hylaeus* bees; and *Odynerus* and *Sierola* wasps.

Three National Parks, HALE, HAVO, and KALA contain a high diversity of the groups mentioned above. Even without extensive systematic sampling, HAVO is known to contain at least 70 species of *Drosophila* (including at least 20 undescribed species), 40 species of *Sierola*, 30 species of *Campsicnemus*, and 20 species of *Hylaeus*. Different suites of species are found in different habitat types, often with a large number of congeneric sympatric species occupying distinct microhabitats. Moreover, the lack of competitors has frequently led to the evolution of globally unique characteristics in Hawaiian species. For example, the Hawaiian insect fauna includes eight of the 12 flightless species of long-legged flies (Dolichopodidae) in the world (derived from two separate lineages); the only cleptoparasitic bees in the family Colletidae; five species of bizarre beetle-like lacewings in the genus *Micromus*; *Eupithecia*, among the only predaceous caterpillars in the world; and several *Drosophila* species that are among the largest in the world. Although relatively few colonists have reached the islands, those that did and speciated profusely in this tiny area often make up a large percentage of the world fauna (*Lispocephala*: over 100 out of 150; *Sierola*: 180 out of about 200; Colletidae: 60 out of about 700; Drosophilidae: about 500 out of 3300, with many more undescribed).

The greatest diversity of Hawaiian insects is in montane wet forest. Kipahulu Valley in HALE, Olaa forest in HAVO, and the Puu Alii area of KALA contain extensive areas of this type. It is the primary habitat of *Campsicnemus* and *Drosophila* flies, and other groups, including *Hylaeus* and *Sierola*, are most diverse there. Damselflies (*Megalagrion*) are also found in wet forest, breeding in small puddles on the ground or in water collecting in the leaf axils of plants. Montane mesic forest also supports a high diversity of native invertebrates. HAVO contains a uniquely diverse area of mesic forest, including at least one species of picture-wing *Drosophila* that is restricted to the area.

Lava tubes – most abundant in HAVO but also found at HALE, KALA, PUHO, and possibly KAHO – harbor unique cave-adapted species, usually independently evolved from surface-dwelling ancestors at each cave complex (Hoch, 1999). These include crickets, planthoppers, spiders, moths, crane flies, earwigs, assassin bugs, and others. The ecosystem of the dark zone is largely dependent on roots of ohia (*Metrosideros polymorpha*) and other trees that extend through the soil and bedrock into the lava tubes.

Coastal and lowland habitats have been highly altered by alien vegetation, invasive ants, and human disturbance, but still harbor unique species, particularly bees and damselflies. The best coastal habitat is found at KALA; the rare coastal bees *Hylaeus anthracinus*, *H. longiceps*, and *H. hilaris* probably occur there, as they are found at the nearby Moomomi TNC preserve (Daly, 2003). Restoration of native coastal shrubland and forest at KALA is underway that may provide improved habitat for these species. Other native coastal areas are found at HAVO, KAHO, and PUHO. An extensive inventory of the insect fauna of KAHO, PUHE, and PUHO in 1992 found few native terrestrial arthropods aside from flies breeding in anchialine ponds. However, it did find several native insects that are specific to the SOC plant *Capparis sandwichiana*, which is relatively abundant at KAHO.

HALE has been the subject of several inventories, including a preliminary resource base inventory of the crater district (Beardsley, 1980) and lower Kipahulu Valley (Smith, 1980). Extensive insect collecting has also been carried out by park staff, and a USGS field research station has supported the work of other entomologists in the park. Extensive elevational and moisture gradients on Haleakala, from sea level to greater than 3,000 m, coupled with the older age of the volcano (compared with Mauna Loa and Kilauea at HAVO), indicate that it should support perhaps the greatest diversity of native arthropods among the parks in the network. This is especially true for the montane cloud forest area of Kipahulu Valley, which has been poorly surveyed for invertebrates but likely contains the highest diversity. The recently-acquired Kaapahu section also contains montane cloud forest. The submontane shrubland of HALE supports the only large population of native cleptoparasitic bees and two bizarre beetle-like lacewings (*Micromus cookeorum* and *M. lobipennis*), but both are threatened by invasive Argentine ants (*Linepithema humile*; Cole, 1992).

The insects of HAVO are the best-studied. Although formal invertebrate inventories have not been done in the park except in selected Special Ecological Areas, the USGS Kilauea Field Station has carried out many research projects on rare and invasive species and on the interaction between invertebrates and birds. These include studies on yellowjacket (*Vespula pensylvanica*) control (e.g. Spurr & Foote, 2000), the effect of rodent control applications on slugs (Spurr et al., 2003), soil invertebrate diversity in pig-disturbed areas, food preferences of exotic and native birds, mosquito-borne avian diseases, and *Drosophila* monitoring. Data from the 1990’s on endemic picture-wing *Drosophila* was compared with survey data from the 1970s IBP surveys and more recent surveys in the 1980s (Foote & Carson, 1995). The results of this retrospective analysis indicate a loss of approximately 18% of the species from Olaa Forest. Similar declines have been noted for damselflies and as a consequence, species of both picture-wing *Drosophila* and *Megalagrion* damselflies have been proposed for listing under the US Endangered Species Act. Other evolutionarily significant groups, including *Odynerus* and *Sierola* wasps, *Lispocephala* flies, and virtually all moths and barklice, are highly diverse in the park but poorly known. Many of these groups face a taxonomic impediment (i.e., undescribed species and a lack of identification keys), but a surmountable one.

The insect fauna of Samoa does not contain highly diversified groups as in Hawaii (Kami and Miller, 1998), but does contain a number of endemic isolates or relicts that are only found in scattered disjunct distributions elsewhere. The Samoan fauna is not well known because recent entomological work has focused almost exclusively on agriculture, and collecting has historically been more intensive in western Samoa than American Samoa. Consequently, NPSA is a high-priority candidate for a park invertebrate inventory.

The island of Guam is estimated to hold about 2,000 of the 10,000 total insect species in Micronesia (Gressitt, 1954). The insects of Guam have been catalogued (Gressitt, 1954) but, aside from agricultural pests, have not been well studied. Although many alien species are present, about 45% of those on Guam are thought to be endemic to the Marianas. The fauna includes 15 butterfly species, of which two are candidate endangered species. One of them, *Vagrans egestina*, was formerly common on Guam but has not been seen there since 1979. The other, *Hypolimnas octucula mariannensis*, is currently known from 10 populations on Guam (another species, *Neptis guamensis*, has not been seen since the type collection in 1916 and is presumed extinct). Both of these species are threatened by a number of factors, including habitat loss due to introduced deer, invasive plants, and development; introduced parasitoids; and unrestricted collecting for the butterfly trade. However, by far the most important factor is the presence of alien ants, which may take 99% of butterfly eggs at times. Since WAPA has not been inventoried for insects, the insect diversity of the park itself is difficult to estimate.

However, since the park is composed of multiple parcels that contain remnant native habitat, it is expected that it contains a significant diversity of native insects. The mangrove wetland at AMME, on the island of Saipan, may contain a significant diversity of insects, but has not been surveyed.

2. Land Snails

Populations of native snails are threatened across the Pacific, largely due to widespread introduction of predators, including the snail *Euglandina rosea* and the flatworm *Platydemus manokwari*. Four rare species of *Partulina* have been found in or near the Puu Alii section of KALA, but none are currently known from other Hawaiian parks. A few groups, such as Succineidae, are still widespread and relatively common in Hawaii. NPSA still has a diverse snail fauna in all units of the park, and the islands of Ofu and Olosega are still free of *Euglandina* and predatory flatworms. Twenty-eight native species were found in a recent survey of NPSA, 23 of which were considered rare (Cowie, 1999). One of them, *Eua zebrina*, is a candidate endangered species. The land snail fauna of the Marianas has been similarly reduced, particularly the Partulidae. This group of snails is widespread in the Pacific Islands, but most species (including all five native to the Marianas) are now endangered or extinct due to alien predators. Four partulids are historically known from Guam, but one (*Partula salifana*) is believed to be extinct, and the other three (*P. radiolata*, *P. gibba,* and *Samoana fragilis*) are very rare and listed as candidate endangered species. In a recent survey (Hopper, 1992), *P. radiolata* and *S. fragilis* were found in or near WAPA. A new population of *P. gibba* was recently discovered at AMME in the mangrove wetland. This species was previously the most common one on Guam but is now nearly extinct there (Hopper, 1992). Discovery of them at AMME is significant because partulids were previously unknown for the area, and were not found on Saipan at all during the last survey of the island (Hopper, 1992). The primary factor in reducing their numbers has been the introduction of alien predatory snails and flatworms in an effort to control another exotic, the giant African snail. With all three native species now occurring in small, highly restricted populations, they are highly vulnerable to development, land clearing, and stochastic events such as fire and typhoons.

3. Streams

Perennial streams are found at HALE, KALA, and NPSA; intermittent streams are also found at HAVO and WAPA. In general, park streams are not well known with regard to invertebrates. However, many aquatic species, especially water-breeding flies, are also able to persist in such places where alien fish are absent, even where the surrounding vegetation and insect fauna is largely alien. An inventory of Waikolu and Waialeia streams in KALA has been done and should be repeated at regular intervals to monitor populations of aquatic insects and snails. Although water from Waikolu is partly diverted for human use, it is relatively pristine for much of its length and contains a diverse native invertebrate fauna. Two candidate endangered *Megalagrion* damselfly species, *M. pacificum* and *M. xanthomelas,* are known from Waikolu stream (Polhemus, 1994). The three major streams of Kipahulu Valley in HALE (Palikea, Pipiwai, and Puaaluu) have had preliminary invertebrate inventories, but the discovery of interesting species in them shows they deserve further study. The damselfly *M. pacificum* is also found in lowland areas of these streams.

4. Anchialine Ponds

Anchialine pools are rare and localized lentic mixohaline waters along coastal lava flows that exhibit tidal fluctuations without a surface connection with the ocean. In Hawaii, these pools were frequently excavated or otherwise modified by Hawaiians to serve as sources of drinking water, baths and fish ponds. National Parks in Hawaii possess the full spectrum of pool types, from walled fish ponds to undisturbed pools in collapsed lava tubes, cracks and caves. Anchialine pools, fish ponds, and other brackish water habitats (hereafter termed coastal lentic mixohaline habitat or CLMH) occur in HAVO, KALA, KAHO and PUHO. CLMH in these parks have been inventoried for vertebrates, crustaceans, and mollusks (Maciolek and Brock, 1974; Chai et al., 1989; Chai, 1991; Brasher, 1996; Brock, 1997; Kinzie, unpubl. data). The crustacean fauna, in particular, has been well-described and a candidate endangered shrimp, *Metabetaeus lohena,* has been recorded from KAHO. In contrast, aquatic insects and other non-crustacean arthropods have not been surveyed until this year. This group includes potential Species of Concern (SOC), such as endemic aquatic Diptera, and one Candidate Endangered Species, the orangeblack Hawaiian damselfly, *Megalagrion xanthomelas* (Polhemus, 1995). This damselfly is currently being listed by the Fish & Wildlife Service and will represent the only federally listed Threatened or Endangered Species (T&E Species) whose life cycle is completed in park anchialine pools. Identified threats to this species include non-native fish, such as guppies (*Poecilia reticulata*), mosquitofish (*Gambusia affinis*), and tilapia (*Oreochromis mossambicus*), and alien odonates, including forktail damselflies (*Ischnura ramburii*) and the roseate skimmer (*Orthemis ferruginea*). The unique lake in Kauhako Crater is considered to be an anchialine pond; it appears to contain species endemic to it, and needs to be examined more thoroughly. A new species of copepod and a genetically isolated population of shrimp (probably *Palaeomon debilis*) were found there in 1999.

PARK AND NETWORK-WIDE ISSUES

Many of the parks share the same or similar issues that threaten their invertebrate (and other) resources. These are presented below, and summarized in Tables 1 and 2.

A. Biological Invasions

Beardsley (1979) reported that, on the average, 15-20 species of immigrant insects become established in Hawaii each year. All parks face threats from these invasive invertebrate species. HALE, HAVO, and NPSA are especially vulnerable because they contain abundant and diverse native invertebrate faunas and are in close proximity to population and agriculture centers, where alien species are most diverse and abundant. HALE and HAVO also have high levels of visitation by off-island tourists. A wide variety of invasive invertebrate pests are already established in the parks, affecting native invertebrates, vegetation, and cultural structures. Predacious social insects have had the greatest impact on native insect faunas (Wilson, 1996). In all parks, alien ants – especially the big-headed ant (*Pheidole megacephala*), long-legged ant (*Anoplolepis gracilipes*), and Argentine ant (*Linepithema humile*) – have had a devastating effect on native insects (Zimmerman, 1978). It is largely because of ants that the native insect fauna of KAHO, PUHE, and PUHO is extremely depauperate. This is the case even where native vegetation persists, and for native insects that can thrive in alien-dominated vegetation. The lowlands of HALE, HAVO, and KALA are similarly affected. Establishment of the Argentine ant in montane areas of HALE and HAVO threatens insect populations in otherwise pristine native habitat (Krushelnycky and Reimer, 1996; Krushelnycky et al., 2004). In WAPA, egg predation by introduced ants is a major factor in the decline of butterflies; in NPSA, alien ants also threaten the diverse native ant fauna of Samoa.

Another widespread problem is of parasitic wasps and flies, both intentionally and accidentally introduced. In the early years of biocontrol little regard was given to the effect of control agents on non-target species, or even their actual role in controlling populations of the target pests. As a result, large numbers of generalist parasitoids were brought into the islands. Although most have not had serious effects, those few that frequently attack natives are among the most influential on native insect populations. Combined with others that were introduced accidentally, they have caused dramatic changes in native species abundance and community composition. Many of the Hawaiian moths that were formerly enormously abundant, such as those in the genus *Scotorythra*, are now much less common, and some species that were rare to begin with may now be extinct. In some areas or seasons, parasitism rates may be close to 100%. The highly diverse native wasps (*Odynerus*) that prey on caterpillars have undergone a similar decline, due to both lack of prey and introduced competitors. Even the effectiveness of more recent, targeted biocontrol efforts for invasive plants has been sharply reduced by high rates of parasitism of the control agent. Although little monitoring of introduced parasitoid populations and their impacts has been done, they are a serious concern that deserves greater attention.

Snails have been the victim of similarly misguided control efforts aimed at the giant African snail, an agricultural pest that is now widespread in the Pacific. The predatory snails *Euglandina rosea* and *Gonaxis* spp. have been widely introduced despite lack of evidence that they control the African snail. These species have been implicated in the decimation of land snail populations in Hawaii, American Samoa, and Guam. In addition, the snail-feeding flatworm *Platydemus manokwari* has been introduced into Hawaii, Guam, and American Samoa. It has virtually eliminated both native and introduced snails (including even *Euglandina*) in many areas, and was probably a major contributor to the extinction of *Partula salifana*. Despite being listed as one of the 100 worst invasive species by IUCN, *Platydemus* is being widely promoted by the FAO for control of the African snail.

The primary threat to anchialine ponds has been from human development, but those in protected areas now face serious threats from invasive species. Mosquitofish (Poeciliidae) have been introduced, or spread on their own, into many anchialine ponds. In most cases, where mosquitofish are found, native invertebrates such as opaeula shrimp are absent. Pickleweed (*Batis maritima*), an exotic salt-tolerant plant, can also cover and choke shallow ponds, trapping sediment and eventually filling them in.

Following the introduction of the brown tree snake to Guam, populations of insect-feeding birds, bats, and reptiles have been reduced or eliminated. This has led to an explosion in the insect and spider populations, with both agricultural and health consequences. The impacts on community structure of native arthropods, and the balance of natives and aliens, is likely to be severe, with consequent effects on native vegetation.

Mosquitoes are major pest insects everywhere. In Samoa and Guam they are important as vectors of human disease. Numerous species are present in Guam; only 5 are native, but over 30 others have been introduced. Among the introduced species are vectors of malaria, dengue fever, chikungunya fever, Japanese B encephalitis and filariasis, all of which known to occur on Pacific islands. Native species are usually not efficient vectors of exotic pathogens, but can transmit Ross River disease, an introduced virus. Although these diseases are not currently a major problem, increases in mosquito populations due to the demise of vertebrate predators and periodic outbreaks of mosquitoes during the wet season make the potential for serious disease outbreaks high. At least 14 species of mosquitoes are found in American Samoa, most of them introduced, and occasional outbreaks of dengue and filariasis occur. Mosquitoes in Hawaii can also transmit many of these diseases, as shown by a recent outbreak of dengue on Maui, but are of greater concern as vectors of avian malaria and pox. These diseases have decimated native bird populations and effectively restrict them to upper elevations where mosquitoes are less abundant.

Assessing the threat posed by incipient invasive species and detecting their presence are important monitoring functions for Pacific Island parks to ensure proactive and cost-effective management. Many threatening species have become established recently in the Parks or on the home islands of the Parks. Others are likely to be introduced to the islands, including some that are present on other islands of an archipelago. For example, *Euglandina rosea* has been introduced to the islands of Tutuila and Tau, but not Ofu and Olosega, where it would have a serious impact on rare native snails. Although a large number of invasive ants are already established, there are other known invasive species (such as the red imported fire ant, *Solenopsis invicta*) that could still cause serious problems.

B. HABITAT LOSS

The loss of plant habitat is the biggest indirect threat to invertebrates. Habitat loss can occur either by direct human destruction or modification, or by transformation as a result of alien plant invasion. Large areas exist in HALE, HAVO, KALA, and WAPA where the native plants have been almost entirely replaced by exotic vegetation; in AMME, KAHO, PUHE, and PUHO very little of the original plant cover remains. In general, most insect species are tied directly or indirectly to the vegetation native to the area. Relatively few native species are found in areas dominated by exotic plants. The majority of plant-feeding insect species, especially in groups that have radiated extensively in Hawaii, are specific to one or a few host plants. Many of their native parasites and predators are specific as well. The result is that a reduction in plant diversity, even where the vegetation remains largely native, results in a dramatic decline in insect diversity, cascading across all functional groups. This is a frequent consequence of feral pig activity in Hawaiian forests, where the diverse species of trees, shrubs, and herbs in the understory are removed, leaving only the relatively few canopy species.

Although development in the parks is extremely limited, adjacent development can have serious impacts on ecosystems within a park. Parks often contain limited areas of certain habitats that are more extensive in nearby areas, and destruction of the latter may be detrimental to park invertebrate populations. An example of this is anchialine ponds on the Kona coast of Hawaii, most of which have been destroyed or invaded by alien fish. A cluster of ponds north of KAHO are now threatened by development; their loss would significantly reduce the size of the *Megalagrion xanthomelas* damselfly population and make it more vulnerable to stochastic events. Development also tends to bring in invasive species that then move into the park.

C. ANTHROPOGENIC POLLUTION

Water diversion and pollution are concerns in several parks. Waikolu Stream in KALA is a major water source for the island of Molokai. Diversion of water significantly reduces the flow of the stream, especially in dry periods, and thus its habitat quality for the rare damselflies *Megalagrion pacificum* and *M. xanthomelas*, as well as other species that breed in the stream. Anchialine ponds at KAHO rely on fresh groundwater influx to keep the salinity level low, but upland wells to supply the growing human population in Kona are reducing the groundwater flow. Pollution is not a major concern as far as habitat quality in most parks, but does affect anchialine ponds at KAHO. The mangrove wetland at AMME and a stream in the park receive saline effluent from a desalinization plant and pollutants from a nearby town, affecting its suitability as habitat for invertebrates.

D. HUMAN HARVEST

Direct human taking is not a concern for most terrestrial and freshwater invertebrate species, but can have a major impact on those where it is. NPSA and WAPA both contain rare species such as snails and butterflies that are or may be traded and sold; like other wildlife, the value of a specimen goes up as the species becomes closer to extinction. Hundreds of thousands of *Achatinella* and *Partulina* snails were collected from Hawaii for their beautiful shells in the past (Hadfield, 1986). It is not known if collecting is currently affecting snail populations in or near any of the National Parks, but it is a concern. Anchialine pond shrimp are collected in west Hawaii, but the impact on shrimp populations is unknown. Coconut crabs are or have been heavily harvested for food on Guam and American Samoa, where subsistence harvesting is allowed in the park. As a result, these populations have declined and the age structure has been altered, with few large adults.

E. RESTRICTED POPULATIONS

Many species have become restricted to small ranges, often in suboptimal habitat, due to the intrusions of invasive species, habitat destruction by humans, or loss of host plants. While small populations might be able to persist in safe havens, they now become susceptible to extinction or extirpation by random, stochastic events that would not be so devastating for a larger, more widespread population. Typhoons on Guam are yearly events, but recent storms that damaged the forest canopy may have been the final blow to the snail *Partula salifana*, which was reduced to a tiny population by introduced predators and now appears to be extinct. *Partula gibba* is known on Saipan only from the small wetland at AMME. Species of *Drosophila* in HALE, HAVO, and KALA are often restricted to a single host plant species, and require rotting plant material to breed. Regeneration of many plants was reduced or eliminated by feral ungulates (pigs and goats), such that some species have few individuals left within the parks. Even when ungulates are removed and plant regeneration begins again, the gap between the death of the older plants and maturity, death, and rotting of the new generation can cause loss of the fly species dependent on them.

F. CLIMATE CHANGE

The linkages between cloudwater hydrology and high species endemism in a narrow altitudinal zone make tropical montane cloud forests (TMCF) in HAVO, HALE, KALA and NPSA, potentially among the most vulnerable to loss of biodiversity through climate change. The most obvious climatic change to be expected during this century is increasing temperature associated with the build up of greenhouse gases in the atmosphere. On Maui, HaleNet, a network of micrometeorological observing stations, has been operating in the national park since 1988 (Loope & Giambelluca, 1998). Using longer term NWS data revealed that the magnitude of the warming at HALE during the last 30 years of the 20th century (3˚C per 100 years) was approximately double that of the global mean (Giambelluca & Foote, 2003). Hydrologic changes with the potential to impact TMCFs appear to be already underway. The ten driest years in the past century in Hawaii all coincided with El Niño winters and we are observing a high frequency of such events currently. Significant reduction in stream base flow is also suggested from long-term data, such as those from Maui and Molokai. Aquatic invertebrates should be monitored first as a means to detect the biological consequences of climate change in national parks. Sea level rise could have serious effects in the west Hawaii parks, where coastal anchialine ponds are an important habitat for native insects in the lowlands. Although species such as shrimp would not be affected, insects such as *Megalagrion xanthomelas* have a limited salt tolerance. Should the balance of fresh and salt water in the ponds change, they could potentially be unable to breed in the ponds. KALA includes remnant coastal strand vegetation, an important habitat for several rare species, that may be affected by rising sea level as well.

Table 1. Major stressors on invertebrate populations (see Park and Network-Wide Issues above for details). ALKA and USAR are not included due to their undefined (ALKA) or extremely limited (USAR) invertebrate resources.

	AMME	HALE	HAVO	KAHO	KALA	NPSA	PUHE	PUHO	WAPA
invasive insects	●	●	●	●	●	●	●	●	●
invasive molluscs	●				●	●			●
invasive plants	●	●	●	●	●	●	●	●	●
invasive vertebrates		●	●	●	●	●		●	●
visitor impacts		●	●		●				
nearby development	●		●	●		●	●	●	●
water diversion				●	●				
water pollution	●			●					
rare plant extinction		●	●	●	●				
human harvest				●		●			
restricted populations	●	●	●	●	●				●
climate change	●	●	●	●	●	●	●	●	●

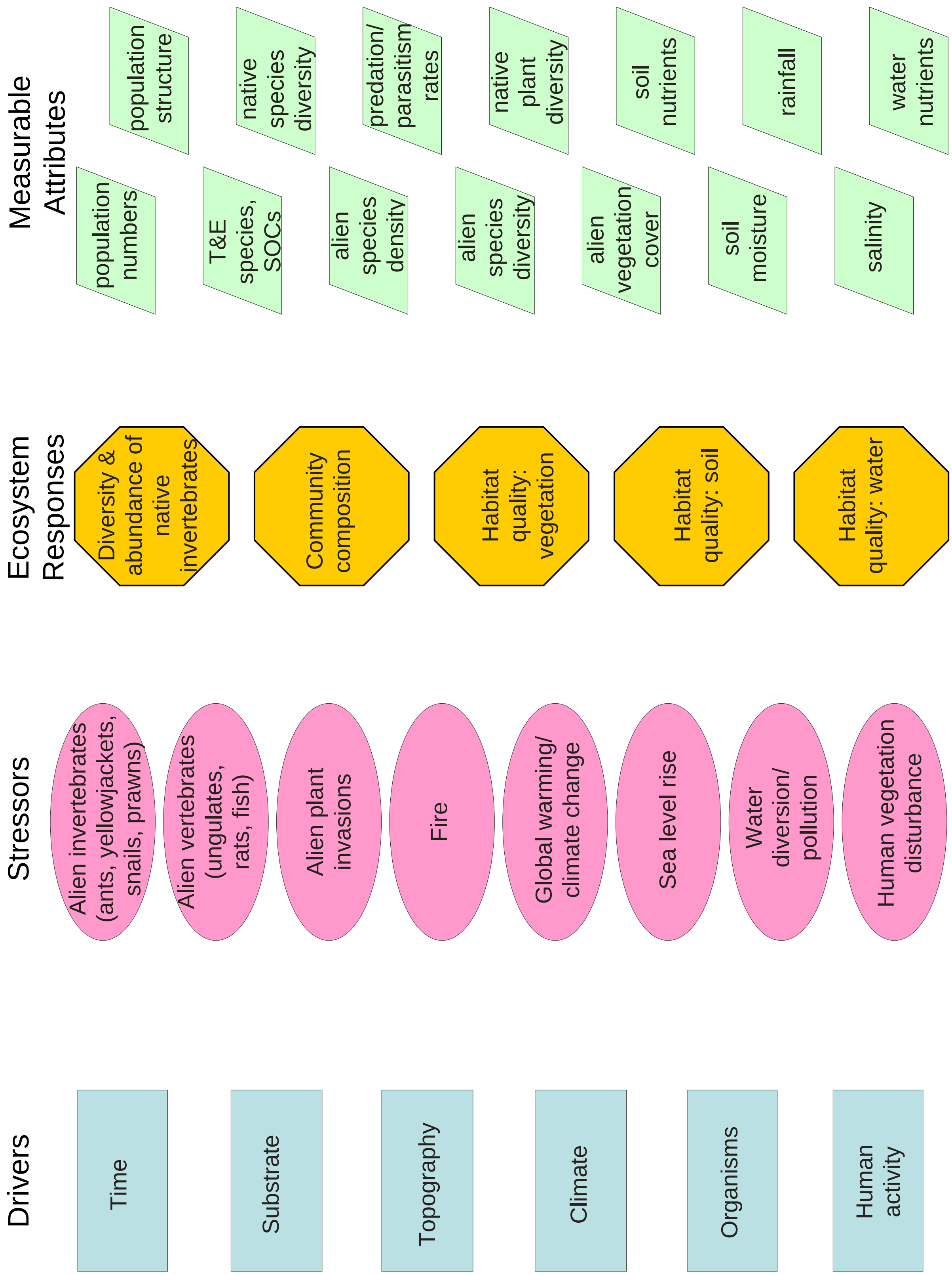
Table 2. Critical invertebrate resources present in parks (see Natural Invertebrate Resources above for details). ALKA and USAR are not included due to their undefined (ALKA) or extremely limited (USAR) invertebrate resources. Question mark indicates potential where resources are not fully known.

	AMME	HALE	HAVO	KAHO	KALA	NPSA	PUHE	PUHO	WAPA
significant taxa									
Drosophila (pomace flies)		●	●		●				
Hylaeus (bees)		●	●	●	●				
Megalagrion (damselflies)		●	●	●	●			●	
butterflies						●			●
land snails	●	?	●		●	●			●
anchialine pond crustaceans			●	●	●		●	●	
other	?	●	●		●	?			?
significant habitats									
subalpine shrubland		●	●						
cliff & summit scrub		●	●		●	●			
bogs		●	●		●	●			
wet forest		●	●		●	●			
mesic forest		●	●		●				
dry forest		●	●		●				
limestone forest									●
ravine forest									●
savannah									●
grassland		●							
anchialine ponds			●	●	●		●	●	
coastal strand			●		●	●			●
coastal swamp	●		●	●	●		●	●	
perennial streams		●			●	●			●
intermittent streams		●	●		●	●			●

CONCEPTUAL ECOLOGICAL MODEL

The conceptual model for invertebrates is presented below (Figure 2). ***Drivers*** and unnatural ***stressors*** are the basic forces that mold ecosystems and cause change in them. ***Ecosystem responses*** are the explicit properties of the resources that are impacted by drivers and stressors, and are the underlying qualities that are measured during monitoring. ***Measurable attributes***, data types that would be collected in order to assess the condition of the ecosystem responses, are suggested. Nearly all drivers and stressors affect all the ecosystem responses shown, and each measurable attribute can be used for monitoring multiple responses. Therefore, links between them are not shown for simplicity. This is a highly generalized model covering all ecosystems. As needed for monitoring implementation, subset models will be constructed for individual islands and ecosystems emphasizing the specific forces at work in them.

Figure 2. Generalized conceptual model for invertebrates in Pacific Island ecosystems.



MONITORING

A. Parks Monitoring

1. ALKA

No monitoring has been done outside the other parks that the trail passes through. The trail will run through HAVO, KAHO, PUHE, and PUHO, but such areas will be handled under the auspices of the existing parks. Elsewhere the path of the trail(s) has not been defined and it is not known what management of natural resources will be undertaken.

Needs: Basic resource management assessment should be done once the trail is defined.

2. AMME

No resource base inventory or monitoring of invertebrates has been undertaken in AMME.

Needs: Priorities are monitoring of the tree snail (*Partula gibba*) population and inventorying other invertebrates in the mangrove wetland.

3. HALE

Monitoring has focused on invasive species, namely the Argentine ant (*Linepithema humile*) and the western yellowjacket wasp (*Vespula pensylvanica*). HALE and its cooperators have been maintaining monitoring programs for these two species since the 1980's. Both of these species are highly damaging to native invertebrates and can potentially be controlled.

Needs: Resource base inventories of invertebrates could be repeated as a form of long-term monitoring of terrestrial communities. Recent inventories of yellow-faced bees (Daly, 2003) could also serve as the basis of a monitoring program for a diverse, yet rare, group of endemic pollinators. Monitoring of both native and alien species is needed for Kipahulu valley, and for pollinators and other insects associated with silverswords (*Argyroxiphium sandwicense*) in Haleakala Crater. Other potential monitoring projects include tracking indicator species in wet forests and streams, and long-term changes in diversity in rain forests, diverse mesic forests, subalpine, and alpine ecosystems.

4. HAVO

A large number of monitoring projects are or have been carried out at HAVO. Long-term, continuous monitoring is being done on the invasive western yellowjacket and two-spotted leafhopper, and on mosquitoes as part of an avian disease project. The wasp monitoring program is proportionally larger than its counterpart at HALE, but serves the same purpose in tracking population size and the efficacy of control programs using insecticidal baits. Two-spotted leafhopper monitoring was implemented following the discovery that it is associated with the decline of native ohia and alien faya tree (*Myrica faya*) centered in seasonal submontane habitats. Mosquito monitoring is being conducted in conjunction with a National Science Foundation Biocomplexity Project to understand vector relationships to avian disease and the decline of native forest birds.

Shorter-term monitoring of select rare invertebrate groups has been conducted along transects in montane rainforests. Taxa were chosen based on ease of identification and previously reported sensitivity to feral ungulate disturbance. These groups include Collembola (springtails) from the soil and litter invertebrate community; *Drosophila* (pomace flies) from the host-plant associated arthropods; and *Megalagrion* damselflies from the aquatic (and semi-terrestrial) insect fauna. Survey work was detailed enough to serve as a baseline for future long-term monitoring efforts. Alien species of springtails and pomace flies have also been enumerated from survey samples and the relative abundance of native and alien members of these arthropod groups have been used as a gauge of recovery following the removal of feral pigs from Olaa Forest. Monitoring of *Megalagrion* damselflies is continuing in the Olaa Forest under the USGS Global Change Program, where these endemic damselflies are studied as indicators of hydrologic change in montane and coastal Hawaiian ecosystems. The soil and litter fauna, including alien slugs and ground beetles, have also been monitored in conjunction with recent tests of rodenticides to control rats using compressed cereal-grain baits. These surveys can serve as the basis future monitoring of these poorly understood groups of invasive invertebrates.

Needs: No efforts has been devoted to monitoring the effects of fire, or the impact of large-scale outplanting and habitat restoration programs, on invertebrate communities in the park. In the case of the former, large-scale changes in ant communities have been reported following fires in lowland areas. In contrast, habitat restoration programs should result in an increased dominance of native host-associated arthropod species. Monitoring of bees and other pollinators of rare plants, such as Mauna Loa silverswords (*Argyroxiphium kauense*) and ohai (*Sesbania tomentosa*), may be called for upon completion of an upcoming research study on rare plant limiting factors. Monitoring of *Drosophila* is currently dormant and should be revived. The Kahuku addition is in need of an invertebrate inventory.

5. KAHO

Populations of *Megalagrion xanthomelas* damselflies breeding in anchialine ponds have been monitored for several years, but surveys for other species have been sporadic. Inventories of other anchialine pond species were recently done.

Needs: Surveys of anchialine pond communities, including trend in invasive species, should be repeated as part of long-term monitoring. Native bees (*Hylaeus difficilis* and *H. anthracinus*) and species associated with *Capparis* and other rare plants are candidates for monitoring. Records of other native insects from the 1992 inventory should be reviewed for species of concern. The area is so dominated by alien insects that virtually any native species found there is a significant discovery. Native plant restoration areas should be monitored for recolonization by native insects. KAHO would serve as a good site to monitor incipient invasions of immigrant arthropods associated with the airport at Kailua-Kona.

6. KALA

No invertebrate monitoring has been done. Inventories of Waikolu and nearby Pelekunu streams were done recently.

Needs: Populations of the two candidate endangered damselfly species, *Megalagrion pacificum* and *M. xanthomelas*, should be monitored. Monitoring programs for *Megalagrion* at HAVO and KAHO could serve as models for similar projects in KALA. Aquatic species in the streams, including damselflies, and wet forest flies are particularly suited to long-term monitoring programs. Other areas, including Waikolu, Waialeia, and Waihanau valleys, and dry forest and coastal strand communities on Kalaupapa peninsula, have probably been invaded by alien ants (*Pheidole* and *Anoplolepis*) but may still harbor native insects, particularly stream-breeding species and rare coastal bees (*Hylaeus*). Extensive plant restoration projects are currently underway in coastal and lowland areas of the park; coincident with these efforts should be monitoring of plants for colonization by both native herbivores and alien pests. An invertebrate inventory of the penninsula, including Kauhako Lake, would likely turn up other species that would be high priorities for monitoring.

7. NPSA

No invertebrate monitoring or inventories have been done.

Needs: A survey of land snails in 1998 (Cowie, 1999) found many rare species and recommended that regular monitoring of native and exotic species be carried out annually, with more comprehensive surveys every five years. Coconut crabs, which are harvested for food, are a high priority for monitoring to understand population levels and trends. The mosquito-borne diseases filariasis and dengue fever are concerns, and may be subjects for control. An inventory of insects in the park is needed; the pristine rain forest within the park suggests a high diversity of native insects will be found there.

8. PUHE

No invertebrate monitoring has been done. An inventory of the park in 1992 found only two native insect species.

Needs: Native plant restoration areas should be monitored for recolonization by native insects. Anchialine ponds should be monitored in coordination with those at KAHO and PUHO. This park would serve as a good site to monitor incipient invasions of immigrant arthropods associated with the port at Kawaihae.

9. PUHO

No invertebrate monitoring. An inventory of the park in 1992 found few native insects aside from pond-breeding flies.

Needs: Native plant restoration areas should be monitored for recolonization by native insects. Anchialine ponds should be monitored in coordination with those at KAHO and PUHE.

10. USAR

Non-marine invertebrate resources have not been investigated. The presence of native insects is extremely unlikely. This park would serve as a good site to monitor incipient invasions of immigrant arthropods associated with the port of Honolulu.

11. WAPA

No invertebrate monitoring or inventories have been done.

Needs: Several issues with high priority for monitoring are present: mosquitoes and disease transmission; outbreaks of insects due to elimination of predators; influence of vegetation change on insect and snail populations; population trends of rare butterfly species and native and predatory snails; and coconut crab abundance and demographics.

B. Established Monitoring Programs

Development of monitoring methods is often a long and tedious process. This is amplified when dealing with long-term projects because of the need for methods to remain as constant as possible across the life of the program. As a result, it is important for protocols to be established properly from the start. Fortunately, the increase in monitoring of invertebrates means that a large number of published protocols are published or otherwise available, including many that have been used within the National Park system. While all of these will require modification for local conditions, their availability as a starting point greatly reduces the preliminary work needed to begin monitoring programs.

Use of invertebrates as indicators for water quality has a long history. Insects with aquatic larvae are often sensitive to relatively subtle changes in the physical and chemical characteristics of the water they inhabit. Shifts in their abundance and species composition create a record of perturbations that may not be caught by direct measurements, which can be influenced by short-term factors. Naiads and larvae of damselflies, stoneflies, mayflies, caddisflies, and others are used extensively in environmental monitoring of streams and pollution management. In the National Park system, aquatic invertebrate monitoring is or has been done in several parks, including Denali and Great Smoky Mountains. A large number of sampling protocols are available from both government and private sources.

Butterflies are another widely monitored group, as they are both charismatic and indicators of general habitat quality. Several protocols, representing different approaches and ultimate goals (e.g. tracking diversity or abundance), are available. Although Hawaii does not have a significant butterfly fauna, several species (both rare and common) are found on Guam and Samoa that could be subjects of monitoring.

As invasive invertebrates have become major problems worldwide, monitoring of them has increased exponentially. Ants and yellowjackets are problems both in the PACN and elsewhere, and monitoring programs for them are already underway in some parks (see above). Other invasive invertebrates are priority candidates for monitoring.

Hawaii possesses a unique cave fauna, mostly inhabiting the lava tubes of younger islands. The evolutionary significance of these species makes them prime monitoring candidates. Previous study of cave insects has produced considerable knowledge of methods that may be used for monitoring, particularly non-lethal ones. In addition, monitoring protocols now in preparation for Mammoth Cave National Park may be adaptable for use here.

C. RESEARCH NEEDS

Protocols based on previous monitoring of *Drosophila*, *Megalagrion*, snails, ants, and yellowjackets can be used as the basis for a range of future monitoring projects, including rare natives and invasive aliens. Systematic surveys of several areas (e.g. upper Kipahulu valley, Kaapahu, Kahuku, NPSA, and WAPA) need to be carried out to determine monitoring needs and priorities. Indicator species, and in some cases associated monitoring protocols, must be determined for many ecosystems. In some cases, rapid identification of indicators and monitoring of their status can serve to track the health of the general fauna where long-term ecosystem monitoring is needed but cannot be done. Monitoring involving plant-insect interactions (recolonization of restored areas, plant limiting factors, pollination) are extremely important to both groups, and will be done in coordination with vegetation monitoring. Investigation of relationships between insects and plants, including the degree of dependence of one on the other, needs to be more thoroughly understood. Members of some important invertebrate groups cannot currently be identified to species, a problem that needs to be at least partially worked out.

CONCLUSION

Invertebrates are often overlooked amid the attention given to more charismatic animals. It is now clear that smaller organisms will not simply "take care of themselves" if the birds and mammals are tended to. With an insect diversity two orders of magnitude greater than that of vertebrates, and lacking all of the environment-modifying mammals characteristic of continental areas, invertebrates are the central animals in the natural ecosystems of the PACN parks. Moreover, with many empty niches due to the small number of original colonists, many Hawaiian insects have evolved unique adaptations, such as the predatory *Eupithecia* caterpillars and beetle-like *Micromus* lacewings. The importance of the Pacific Island fauna, both for its global significance and its local ecological role, is immense.

The potential of invertebrate monitoring in the Pacific Islands parks has yet to be realized. Although it has taken some time for the importance of the "little things that rule the world" to be recognized, the opportunity now awaits to use them as part of a comprehensive monitoring plan. Monitoring of invertebrates can be used to track changes in the populations of native, alien, and rare or sensitive species; detect incipient or encroaching invasives; and pick up early warning signs of environmental change by using indicator species. Like vegetation monitoring, native and alien invertebrate surveys are an important part of long term monitoring for tracking the health of native ecosystems, such as documenting recovery after feral ungulate removal. A monitoring system will provide resource managers with information essential to tracking invertebrate biodiversity, information that currently is largely lacking. Monitoring programs for established alien invertebrates also serve as the basis of integrated pest management programs that can be readily combined with other alien species detection and control efforts.

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